Proceedings
Seventh International Congress
International Association of Engineering Geology

5-9 SEPTEMBER 1994 / LISBOA / PORTUGAL

Editors

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LNEC, Lisboa, Portugal

OFFPRINT

A. A. B ALKEMA / ROTTERDAM / BROOKFIELD / 1994

7th International I AEG Congress/7™ Congrès International de AIGI© 1994Balkema, Rotterdam, ISBN 90 5410503 8*

Study of the access tunnel to the powerhouse of the Guavio Project (Gachalá, Colombia)

Etude du tunnel d'accès a la centrale souterraine de Guavio (Gachala, Colombie)

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ABSTRACT: *The access tunnel to the powerhouse of the Guavio Project in the East Andean Cordillera of Colombia was excavated between august 1982 and december 1984. The tunnel has a horseshoe section of 52 m2, a total length of 2077 m, a difference in elevation of 206 m, a 12% grade, and the shape of an n In ground plan. It was constructed within marine sedimentary rocks of Cretaceous, Jurassic and Triassic age. The strata are steeply dipping, fractured and jointed, and a large regional fault is crossed near the portal. A comparison was made between the anticipated geological conditions and the conditions that were found, using the Bieniawski Geomechanics Classification of Rock Masses. The optimum advance rates for the rock types were estimated with the tunneling experience in Colombia and these were compared with the actual rates. The article describes and discusses the results of this case history.*

RESUME: *Le tunnel d'accès a la caverne souterrain de le projet Guavio dans la Cordillère Orientale des Andes de la Colombie était excavée entre août 1982 et décembre 1984. Le tunnel a une section de 52 m2, une longueur totale de 2077 m, une dénivellation de 206 m, une pente de 12 %, et la forme d'une n dans le plaine horizontale. II était construe dans roches sédimentaires marins du Crétacé, Jurassique et Triasique ages. Les strats c'est sont fortement inclinées, fracturées et diaclases, et sont traverses par une faille régionale presque du portal. Une comparaison c'est fait entre les conditions géologiques anticipées et les conditions trouves, avec 1'employe de la Classification Geomechanique de Bieniawski. Les mesures d'advance optimum pour les classes de roches c'est sont estimées merci a l'experience de construction des tunnels dans la Colombie et ils c'est sont comparées avec les mesures actuelles. L'article décrire et discute les résultats de cette étude de cas.*

1 INTRODUCTION

During the recent past several large hydroelectric plants with underground powerhouses have been constructed in Colombia, such as Calima and Alto An-chicaya in the Western Cordillera, and Guatape and San Carlos in the Central Cordillera. The powerhouse of the Guavio Hydroelectric Project, recently completed, is the first excavated in the Eastern Cordillera. While the others were excavated in Igneous or metamorphic rocks, the Guavio Project is in sedimentary rocks, so that it has a special interest.

Following is a brief study of the access tunnel to the powerhouse of the Guavio Project, as a contribution to Theme 6, Case Histories in Underground Workings, of the 7th Congress of the International Association of Engineering Geology. This article is a summary of a report prepared for the construction firm, the CAMPENON BERNARD-SPIE-BATIGNOLLES CONSORTIUM in January of 1985, and published with their authorization. (Lobo-Guerrero 1985).

The tunnel was studied after the construction, consulting the documents listed in the chapter on references, examining the geological conditions that were indicated in the tendering documents, the construction records, and the unlined parts of the tunnel. A comparison was made between the anticipated geological conditions and the geological conditions that were found, using the Bieniawski Geomechanics Classification of Rock Masses. The optimum advance rates for the rock types encountered were estimated with the tunneling experience in Colombia and these were compared with the actual construction rates.

2 THE TUNNEL

The CAMPENOM BERNARD-SPIE-BATIGNOLLES CONSORTIUM recently completed the construction of the penstocks, the underground powerhouse, and the tailrace tunnel of the Guavio Hydroelectric Project for the EM-PRESA DE ENERGIA ELECTRICA DE BOGOTA, in the vicinity of Mámbita, Cundinamarca, Colombia. As part of the work the access tunnel to the underground powerhouse was excavated by the new Austrian tunneling method between august of 1982 and december of 1984. This tunnel has a horseshoe section of 52 m2, a total length of 2077 m, a difference in elevation of 206 m, a 12 % grade, and the shape of an "n" in ground plan (see Figure 1). The portal is at elevation 698,00 m while the far end is at elevation 491,67 m. The surface topography rises to a maximum elevation of 1290 m above the tunnel, on the western hillside of the Trompetas River valley, a tributary to the Guavio River.

3 REGIONAL GEOLOGY

The tunnel lies within marine sedimentary rocks of the Cáqueza and Batá Formations, on the eastern flank of the Quetame Massif. (INGEOMINAS, 1975; EEEB, 1981). (See Figure 2).
The Cáqueza Formation (Cretaceous-Jurassic) is represented in the area by two members, the Middle Member and the Lower Member, separated by the Santa María Fault. The Middle Member (Berriasian), with a total thickness of 500 m, consists of shales and sandstones with siltstone and conglomerate lenses intercalations, in the upper part; and of soft, laminated shales, with siltstone intercalations, in the basal part. The Lower Member (Tithonian), with a thickness of 120 m, consists of black siliceous shales, with thin to laminar bedding. It lies in stratigraphic disconformity over the Batá Formation.

The Batá Formation (Jurassic, Líassic -Tríassie, Rhaetian), has three members. The Upper Member, some 300 m thick, consists of black and dark gray, fossiliferous, shales and siltstones, with thin to laminar bedding, and thin layers of dark gray and light gray sandstone. The Middle Member, some 380 m thick, consists of intercalated sandstones, conglomerates and argillites, of greenish gray and red colors. The Lower Member, 460 m thick, consists of red and gray quartzitic sandstone, with intercalations of red argillites and a dark gray limestone in the center part. The Batá Formation lies in stratigraphic disconformity over the Farallones Group (Carboniferous-Devonian).

The Cáqueza and Batá Formations dip between 58°and 82° east along the eastern flank of the Quetame Massif. The Santa María Fault is a regional high-angle thrust fault that separates the Middle and Lower Members of the Cáqueza Formation near the portal.

Rock outcrops at the surface are scarce. There is a thick and very permeable colluvial mantle covering most of the western hill slope of the Trompetas River valley, and a thick zone of rock weathering up to a depth of 100 m. Near the surface there are frequent dip reversals in the strata due to gravitational sagging. This area forms part of the Llanos piedmont with a mean annual rainfall between 3000 and 4000 mm.

4 TERRAIN TYPES

The excavation works and the setting of supports and linings are related to the conditions of the ground, so the designer of the tunnel classified the terrain according to the following parameters: rock type, description of the rock behavior under certain prescribed conditions of excavation and support systems, influence of water inflows on the behavior of the terrain, and the sequence of excavation and support (EEEB, 1981). Following is the definition of the five types of terrain:

a) Type I Terrain. This classification corresponds to sound rock, little fractured and stable, where the excavation can be made without needing any support at the excavation face. In this type of terrain water Inflow can be very high at the face, but concentrated to the length of open fractures without any influence on the stability. Due to security reasons it may need the installation of isolated rock-bolts or the sporadic application of shotcrete. In this type of terrain the tunnel can be excavated in one stage, without restriction of distance between the face and the support that has been mentioned.

b) Type II Terrain. This classification corresponds to hard rocks with thin bedding, fractured to moderately fractured, and to hard shales with thick bedding. In this type of terrain there is a tendency to sloughing with time with the opening of fractures or bedding planes; furthermore, shales and siltstones tend to weather in the presence of air. Infiltrations nay be high, but their influence on the stability of the tunnel is not of large importance, being limited to small local rock falls. In this type of terrain the tunnel can be excavated in one stage with the limitation of a maximum advance of 3 meters per cycle. The support consists of shotcrete, rock bolts and metallic mesh.

c) Type III Terrain. This classification corresponds to hard, very fractured rocks, and to hard shales and siltstones with thin bedding, and to colluvial or alluvial deposits. In this type of terrain the material tends to slough at the face and does not allow the excavation of the full section, so that the upper section must be excavated first and then the lower section. In the case of shales it is possible to have slight ground pressure. Infiltrations, although moderate in magnitude, considerably increase sloughing and should be controlled immediately. The support consists of shotcrete, metallic mesh, structural steel sets, and rock bolts.

d) Type IV Terrain. This classification corresponds to soft or altered rock, with cohesion, that has a low strength with relation to the overburden and produces ground pressures, that in the presence of inadequate support cause sloughing of the walls, Intense cracking of the lining, and in certain cases, swelling of the invert. In this type of terrain the magnitude of infiltrations is low but their influence is large on the behavior of the excavation, because the pressure increases as the strength of the material decreases and sloughing intensifies at the face. In this type of terrain the tunnel must be excavated in three stages: upper section, lower section, and invert section. The support consists of shotcrete, metallic mesh, structural steel sets, rock bolts and a concrete invert.

e) Type V Terrain. This classification corresponds to soft or altered rock, intensely folded and fractured, where, if the support is Inadequate, one finds intense ground pressures and invert heaving. In some cases it is necessary to excavate a larger section to allow controlled deformations before proceeding to place the final shotcrete lining. Infiltrations have a large influence on the behavior of this type of terrain, up to the point where it looses all its cohesion. In this type of terrain the tunnel must be excavated in three stages: upper section, lower section and invert section. The support consists of shotcrete, metallic mesh, rock bolts, structural steel sets and a concrete invert.

5 EXPECTED GEOLOGICAL CONDITIONS

5.1 Interpretation

One of the objectives of the tunnel study was the establishment of a balance along the entire tunnel comparing the expected geological conditions and the encountered geological conditions. When the study was performed the tunnel was already constructed, so the balance is supported by all the technical documents prepared before the excavation and during the excavation, by the Consultants, the Constructors and the Inspectors, plus the information provided by a visit underground to the tunnel.

It was decided that the best method of preparing the balance was to translate in comparable numerical terms the anticipated geological situation and the one encountered by means of the Geomechanics Classification of Rock Masses, developed by Z.T. Bieniawski for the South African Council For Scientific And Industrial Research. There are several other rock mass classifications for tunnels but this one was selected because of the type of basic information available. In his original publication (1974), Dr. Bieniawski stated: " A classification system for rock masses is essential to ensure understanding and communication among those concerned with a given tunneling project, such as the Employer, the Engineer, the Contractor, the Rock Mechanics Engineer and the Engineering Geologist. A classification system is also important in designing the route and tunnel cross-sections, drawing up preliminary cost estimates, determining the construction time, tendering, choosing the methods of excavation and temporary support and evaluating experiences obtained during construction. In general, a rock mass classification has the following purposes in a tunneling application:

1) To divide a particular rock mass into groups of similar behaviour;
2) To provide a basis for understanding the characteristics of each group;
3) To yield quantitative data for the design of tunnel support;
4) To provide a common basis for communication. "

Bieniawski's Geomechanical Classification has been tried out and adjusted both in tunnels and in mines in many countries during the last twenty years. It has proved to be a very good empirical tool for design purposes. The Classification in the 1984 version is presented in Table 1 (Bieniawski, 1984).

5.2 Geomechanics Classification of the Expected Conditions

Figure 3 is a longitudinal geological profile of the Access Tunnel with the anticipated conditions of formations, rock quality, and class of support and water inflow. The figure is modified from a report prepared by Prof. Dr. G. Spaun, when he studied the tunnel in progress during October of 1984 (Spaun, 1984). On the bottom is the geomechanics rock classification with the Bieniawski method, as one would have interpreted the information available at the moment of tendering. The tunnel has been divided into nine zones of similar geotechnical properties and topographic orientations. Following is a description of each zone and the selected ratings. The information is summed up in Table 2.

5.2.1 Zone 1, Portal to Km 0 t 200

The portal would be excavated partially in talus and in rock, composed by shale, dipping 35" to 45" toward the MW. The rock would be somewhat fractured and altered by weathering. Later on, between the portal and Km 0+200 m the excavation would be in shales and siltstones with some conglomerate layers and occasionally sandstones, of the Middle Cáqueza Formation (Kicm); in general, the shales would be weathered and fractured with abundant slickenside and frequent clay zones due to weathering. The state of weathering of the rocks other than the shales is not indicated, but one can suppose that it is similar. Hater inflows of 60 1/s were estimated in this stretch. Drill hole PT-M-5 intersected these rocks and found them very weathered and very fractured, including the lithologies mentioned above and a 3m thick limestone. The conglomerates have a moderate compressive strength (59,4 to 101,2 MPa), and a RQD of 75% to 100% The intermediate shales are soft and fractured. A rating of 15 points in Bieniawski's Geomechanics Classification (Table 1) was assigned to this jointed rock mass, which means a very poor rock (also see Table 2).

5.2.2 Zone 2, Km 0 + 200 to Km 0 + 275

In this zone black overturned shales were expected, dipping from 50° to 80° W, very altered to clay, partly calcareous, very soft to moderately hard, fractured and folded; alternating with siltstone layers, and with occasional calcite veins, some gypsum and pyrite; with abundant slickenside. Drill hole PT-H-8 investigated these materials. The only core that was tested, a black siltstone, had a uniaxial compressive strength of 46,1 MPa (moderate strength). The shale’s have a low RQD, with an average of 30% while the siltstones have a high RQD, with an average of 80%. A rating of 25 points, poor rock, was assigned to this rock mass.

5.2.3 Zone 3, Km 0 + 275 to Km 0 t 310

Zone 3 is the Santa María Fault. It would be crossed in 30 to 40 m of breccias consisting of soft clay shale fragments, with gypsum veins and calcite, pyrite and quartz nodules. Since the trace of the fault is masked by terrace and talus material, Note 3 of drawing Ref. 091-2455 specifies that the trace on the map is inferred and the zone of influence should be taken within an area of 100 m on either side of the lineament. Drill hole PT-M-7 investigated the fault between 40 and 380 feet. A rating of 10 points, very poor rock, was assigned to this material.

5.2.4 Zone 4, Km 0 + 310 to Km 0 + 480

According to the document on geology this stretch would cross the Lower Member of the Cáqueza Formation (Kiel) consisting of dark gray shale striped with thin and irregular siltstone and light gray sandstone fractured to moderately fractured, with estimated water inflows of 60 1/s. A normal dip of 70°SE was expected. The basal part of drill hole PT-M-7 and drill hole PT-M-10 investigated this zone. The shales and siltstones have a RQD that varies from moderate to very high (40 - 100%) and although there are no uniaxial strength analysis one can assume that these rocks have a moderate strength. A rating of 29 points in the Geomechanics Classification, poor rock was assigned to this material.

5.2.5 Zone 5, Km 0 + 480 to Km 0 + 770

According to the tendering documents this zone would be composed by dark gray to black shales and siltstones with some light gray sandstones, the JR3 Member of the Batá Formation, dipping some 70°SE, and with estimated water inflows of 30 1/s. Drill hole PT-M-3 investigated the basal part of this unit finding fractured to very fractured rock, with a low RQD of 10 to 50%. The uniaxial compressive strength is low in general, and varies from 1.9 to 60 MPa. A rating of 29 points, poor rock, was assigned to the zone.

5.2.6 Zone 6, Km 0 + 770 to Kit 1 + 000

According to the document on geology this zone would be composed by red quartzose sandstones of the JR2 Member of the Batá Formation, with some argillite intercalations and lenses and beds of conglomerate of "excellent character–ristics", with dips of 70° SE and a fair amount of water. The uniaxial compressive strength varies from 53,6 to 158,0 MPa (moderate to high strength), and a high RQD from 75% to 100%. The argillites have a compressive strength that varies from 16,8 to 67,5 MPa (low strength). A rating of 69 points, good rock, was assigned to this zone.

5.2.7 Zone 7, Km 1 + 000 to Km 1 t 500 (S75°W orientation)

According to the document on geology this zone would also have rock of "excellent characteristics", similar to the previous one. The rocks would dip 70°SE forming an angle of 30°to 40° with respect to the tunnel alignment. A rating of 69 points, good rock, was assigned to this zone.

5.2.8 Zone 8, Km 1 + 500 to Km 1 + 600

The Access Tunnel would penetrate rocks of the JR1 Member, sandstones and red conglomerates of "excellent characteristics", in a short segment of the second curve. These were also rated as good rock.

5.2.9 Zone 9, Km 1 + 600 to Km 2 + 100 (S10°E orientation)

The final stretch of the tunnel would cross gray to green quartzose sandstones with some argillite intercalations and conglomerate lenses and beds, of the JR2 Member, dipping 70°SB, with an estimated water inflow of 500 1/s. Drill holes PT-M-9 and PT-M-3 investigated these rocks; in general they have a high RQD, 90-100%, and a uniaxial compressive strength that reaches 104,6 MPa (moderate to high strength). A rating of 75 points, good rock, was assigned to the zone.

6 GEOLOGICAL CONDITIONS AND DIFFICULTIES ENCOUNTERED DURING THE TUNNEL EXCAVATION

6.1 The Portal Site

The portal was relocated 35 m to the NNE of the original site, placing it only 25 m away from the Caño Tigre stream. The work was interrupted in two opportunities by floods of Caño Tigre: from november 14 to 28 and from august 27 to September 3 of 1984. During the rainy season a landslide fell on the stream and this diverted the waters toward the tunnel. In total the work was delayed 20 days due to the flooding of Caño Tigre.

6.2 Encountered Geological Conditions

The lithologic conditions and the principal orientations of the discontinuities and the lithostratigraphic units are il–lustrated in the longitudinal geological profile of Figure 4. On the graphs under the profile are represented small faults, the Santa María Fault Zone, the classes of support that were placed, the degree of fracturation according to the Müller-Hereth classification, actual water Inflow, the excavation advance in m/day, and finally, the geomechanical classi–fication of the rocks. Following is the description of the twelve zones of similar geotechnical characteristics that were found. There are no detailed geological descriptions of the first 900 m of the tunnel. The ratings are presented in Table 3.

6.2.1 Zone 1, Portal to Km 0 t 154

Zone 1 was excavated from October 1, 1982 to June 27, 1983, in very poor rock, consisting of weathered shales and siltstones with little water, and the Santa María Fault Zone. The excavation was very difficult, in half-section, with the installation of type IV support, without any advance during the month of October of 1982. During november only 27 m had been advanced, 24 m in December, 17 m in January, 27,5 m in February, and 13,2 m in March. A large collapse occurred on april 4, at a distance of 108,5 m from the portal, in the weakest part of the Santa María Fault Zone, and two months were necessary to pass this point. Finally, after the installment of type V support in the fault zone, on June 1 the excavation was resumed, advancing at a rate of 1,69 m/day with type IV support until better ground was found at abscissa Km 0 + 154. This zone was classified as very poor rock, in the Geomechanics Classification. From the point of view of the excavation, the proper breccia zona was found 180 m before expected according to the tender documents, contributing to the problems of this zone (see Table 3).

6.2.2 Zone 2, Km 0 + 154 to Km 0 + 222

From June 11 of 1983 to July 11 the excavation advanced at a rate of 2,2 to 2,6 in/day in locks of a little better quality, with trickles of water, installing type III or type II support. This zone found medium grain black sandstones and shales of the Lower Member of the Cáqueza Formation (Kiel), of moderate strength, strongly dipping to the SE. They were classified as poor rock.

6.2.3 Zone 3, Km 0 t 222 to Km 0 + 508

The black shales (siliceous argillites and hard siltstones) of the base of the Cáqueza Formation were pierced from July 11 to august 22, dipping 62°SE, with a moderate strength, dry, greatly Increasing the rate of advance from 5,71 m/day to 7,66 m/day. This terrain had good self-support so it only needed some 10 cm of gunite at the crown and 5 cm at the walls. This terrain was rated with 64 points, which is a good rock. The best monthly advance rate of the whole work was obtained in these rocks (217,5 m/month), which is a good indication of the constancy of the geomechanical conditions, which helped the excavation of the tunnel in this stretch.

6.2.4 Zone 4, Km 0 + 508 to Km 0 + 965

Black argillites alternating with black siltstones and a few beds of black fine-grained sandstones, of the JR3 Member of the Batá Formation, dipping 58°SE, were crossed from august 22 to november 7. These are strata with moderate to severe jointing, dry or with minor localized dripping, that allowed for advances from 3 m/day to 10,3 m/day, the maximum rate obtained in the tunnel (sept.3/ 83). The rock quality decreased after abscissa Km 0 + 600, probably due to an increase in the fracturation. Several stretches had to be lined with type III supports. The zone was rated with 52 points, corresponding to a fair rock.

6.2.5 Zone 5, Km 0 + 965 to Km 0 t 980

From november 14 to 28, within the first curve, the tunnel cut a rock with extremely high jointing, dry, with soft altered black shale, at the base of the Upper Member of the Batá Formation (JR3). It is un-conformable with an inclination of only 10"SB on JR2 conglomerates. This rock was rated with 20 points; this is very poor rock. It was lined with type III support, including up to 20 cm of gunite, 7 rock-bolts per meter and steel arches.

6.2.6 Zone 6, Km 0 + 980 to Km 1 + 100

From november 28 of 1983 to January 30 of 1984 the tunnel advanced with great difficulty in dark gray quartzitic sandstones, with minor intercalations of somewhat calcareous siltstones and thin beds of black argillites, with high to very high jointing, mostly dry. They dip 75°SE. This is the upper part of the Middle Member of the Batá Formationon(JR2). This stretch has rock rated with 52 points, fair rock. It was lined with type II and I support. The factor that most contributed to the low performance was the lithologic variability in very short lengths. In reality this member is not homogeneous like member JR3, but its characteristic is litholoqic heterogeneity, presenting sandstones, calcareous siltstones and argillites, alternately in thick or thin beds, each one of them with different geomechanical properties. This obviously delays the expected performance of 4 m shots in what was supposed to be rock of "excellent characteristics". When drilling sub vertical rocks with this type of bedding, (and consequently, of fracturation), the drilling speed is less than in massive and compact strata, the blasting performance is less than in compact rock, the mucking operations are longer, etc. This rock is naturally cut up in separated fragments less than 50 cm Iong, according to the Müller-Hereth fracturation classification that was used to describe the degree of jointing.

6.2.7 Zone 7, Km 1 + 100 to Km 1 t 485

After the first curve, the B Section of the tunnel advanced very irregularly from January 30 to July 20 with a rate from 0,57 m/day to 4,66 m/day. The rocks were of the same type of those already described for Zone 6 (Middle Member of the Batá Formation, JR2), dipping from 70° to 82° SE, with very variable joint patterns. Thin zones of faulted rock, in several directions, and a considerable amount of water started to appear. This groundwater, foreseen in general by the tendering documents, flows from the fractured zones and the bedding planes. The

Batá Formation, specially in members JR1, JR2 and JR4, has proved to be an important aquifer in the Chivor penstock tunnels, 20 km to the north, and this character is confirmed in the Access Tunnel to the Guavio Project and surely in the area of the underground powerhouse and its shafts. These rocks were rated with 46 points, being classified as fair rocks, of lesser quality than those of the previous zone. Actually, they had to be supported with from 5 to 15 cm of shotcrete, 7 rock bolts per meter and others along the walls and mesh along the crown In the first half of the stretch, with type II support and later type I in the second half. The low performance that was obtained again has its logical explanation in the fracturation of the rock mass, its variability, and the water inflows. In any case, this rock is not a "rock of excellent characteristics".

6.2.8 Zone 8, Km 1 + 485 to Km 1 + 566

The second curve lies in rocks of the uppermost part of the Lower Member of the Batá Formation (JR1). It consists of red sandstones and calcareous siltstones alternating with quartzitic pebble conglomerates. Several small faults were crossed again and the natural jointing was variable from high fracturation to extremely high fracturation up to abscissa Km t 542, and then low fracturation when the conglomerates are left behind and the tunnel passes to gray and red siltstones, partly high in calcareous content. There was plenty of groundwater in the sandstones, calcareous siltstones and conglomerates, while the sector with gray and red silt-stones is dry. The advance was slow from July 21 to august 20 with an average of only 2,7 m/day, due to the same causes already mentioned: excessive jointing, rapid lithologic changes and abundant water, which conduced to work with flooded faces. The orientation in the second curve is unfavorable, so 10 points were discounted as a rating adjustment for discontinuity orientation. This stretch was rated with 40 points, poor rock. The support that was installed was of type I, although in the most fractured sector it needed 5 cm of shotcrete and 4 to 5 rock bolts per meter in the crown.

6.2.9 Zone 9, Km 1 + 566 to Km 1 + 690

Starting section 3 of the tunnel with direction S10°E it crossed gray and red siltstones of low fracturation, dipping 80°SE, dry, where the advance was quicker. Further on they found again fine-grained reddish sandstones, a conglomerate and gray and red siltstones with local abundant calcareous cement (JR2). The degree of fracturation increased from low to moderate and high, and once more there was abundant groundwater in the most jointed sector. The advances increase slightly with respect to zone 8, and reached a maximum of 5,66 m/day. However the same problems that were mentioned for zones 6, 7 and 8 continued delaying the work, even though excavation driving with steeply dipping beds is very favorable. The rocks were rated with 56 points, which is fair rock. The support was of type I, although the last 65 m had a few centimeters of shotcrete in the crown.

6.2.10 Zone 10, Km 1 t 690 to Km 1 + 710

A fault with very fractured rock and 10 1/s of water inflow was crossed during the week that ended on October 8. The zone was supported with shotcrete and metallic mesh. This stretch was rated with 20 points; very poor rock.

6.2.11 Zone 11, Km 1 + 710 to Km 1 910

From October 8 to november 21 the tunnel advanced in gray quartzose sandstones, sandy siltstones, and siltstones, in medium-thick to thin strata, small faults, and in general, rocks with high to moderate fracturation, dipping 70° to 75°SE. Water inflow was continuous through faults, joints and bedding planes. The rate of advance was similar to that of zone 9. The material was rated with 54 points; fair rock. Type I support was placed.

6.2.12 Zone 12, Km 1 + 910 to Km 2 + 077

The final part of the Access Tunnel, including curve 3, was excavated from november 21 to the end of december of 1984, in siltstones and greenish-gray sandstones, with numerous small faults and a high degree of fracturation. Quartz veins were frequent. The first 90 m of this zone were strongly dripping or flowing, but the rest was dry. The excavation work accelerated from 5,8 m/day at first to 9,5 m/day toward the end. The stretch was rated with 61 points; good rock. Type I support was placed.

7 BALANCE BETWEEN ANTICIPATED AND ENCOUNTERED GEOLOGICAL CONDITIONS

A balance is presented on Table 4 between the anticipated geological conditions (Table 2) and the encountered geological conditions (Table 3).

According to this comparison it was found that the encountered geological conditions were 9 % worse than those anticipated. Furthermore, comparing the classification by terrain (support) and the Geomechanics Classification of Figure 4, one finds that these two are not equivalent. Type I Terrain (Class of Support 1) can include Rock Classes II, III and even V; Type II Terrain (Class of Support 2) can include Rock Classes III and IV; and Type III Terrain (Class of Support 3) can include Rock Classes IV and V.

8 PERFORMANCE

The Contractor calculated the advance rates and the total construction tine according to the information contained in the tendering documents on rock quality, water, and geometric characteristics of the work (length, section and grade). The advance rates of Table 5 and a hypothesis on the distribution of the terrains of Table 6 were made according to the different types of terrains, I to V. The estimate on total execution time (20 months) was consistent with that requested by the EEEB in the tender.

However, as will be seen in the following, the advance rates in Table 5 are not realistic within the experience in Colombia, unless the concept of type of terrain was mistaken for the concept of rock mass class. In the first case, although the general type of rocks and the general effect of groundwater is mentioned in the respective terrain, the terrain classification is basically a description of five different types of excavation systems and of ground support. The rock mass class is defined in Table 1.

There is a great difference between a classification of terrain, where several concepts of construction and final support are mixed with some properties of the rocks, and a classification where the geo-mechanical characteristics of the rock mass are established with the purpose of designing the best type of support, in what is still an art, the art of tunnel construction. The frequent reclamations and basic differences of opinion in this field arise in many cases from a deficient communication within a narrow conceptual frame.

Unfortunately there is very limited published technical information on tunnel advance rates In Colombia, according to the diverse classes of rocks and much less on the diverse types of terrain. The experience of tunnels of several diameters in the hydroelectric projects of Alto Anchicaya, Calima, Chivor, Mesitas, San Carlos, Guatap6 and Chingaza, has been collected in a graduate thesis of the School of Engineering of the Universidad Nacional: Castellanos, Estrada y Jaimes, 1981. Figure 5 is reproduced from this important document. This figure shows advance curves for Colombian tunnels constructed in different diameters, in five different types of rocks: very good, good, fair, poor and very poor rock), according with Barton's (NGI) rock classification for tunnels. Assuming that the five classes of rocks are approximately equivalent in Barton's and Bieniawski's classifications, the exercise of calculating the execution time for the access tunnel with the information of Table 3 and the advance rates of Figure 5, is presented on Table 7.

The tunnel was built in 28 months. If one discounts the time lost by the Caño Tigre floods, one arrives to an actual time of 27,3 months, which is exactly the time estimate of Table 7.

9 REFERENCES

Barton, N. 1976. Recent experiences with the Q-System of Tunnel Support Design. Exploration for Rock Engineering, ed. Z.T. Bieniawski: 273-289. Johannesburg: Balkema.
Bieniawski, Z.T. 1974. Geomechanics classification of rock masses and its application in tunnelling. Tunnelling in Rock: 89-103. South African Council For Scientific and Industrial Research,Pretoria.
Bieniawski, Z.T. 1984. Rock Mechanics Design in Mining and Tunnelling. Rotterdam: Balkema.
Castellanos, J.F., Estrada, A. y Jaimes, P. 1981. Costo de tuneles en Colombia. Proyecto de Grado Universidad Nacional de Colombia. Bogota D.C.
Empresa de Energia Electrica de Bogota 1981. Proyecto Hidroeléctrico del Gua-vio, Licitación G-011,

Conducci6n y Central Subterranea, Información de Referencia y Pliego de Condiciones. Bogota D.E.

INGEOMINAS 1975. Mapa Geológico del Cuadrángulo K-12, Guateque, Colombia. Escala 1:100.000; Informe 1701. Bogota D.E.

Lobo-Guerrero, A. 1985. Informe técnico-geológico relativo a la excavación del tunel de acceso a la Central Subterranea del Proyecto Guavio. Informe presentado al CONSORCIO CAMPENON BERNARD-SPIE-BATIGNOLLES. Bogota D.E.

Spaun,G. 1984. Report about expected and encountered geological and tunnelling conditions in the access tunnel; report prepared for the CONSORCIO CAMPENON BER-NARD-SPIE-BATIGNOLLES. Ainring.